Soil and Soil Survey

A soil survey describes the characteristics of the soils in a given area, classifies the soils according to a standard system of classification, plots the boundaries of the soils on a map, and makes predictions about the behavior of soils. The different uses of the soils and how the response of management affects them are considered. The information collected in a soil survey helps in the development of land-use plans and evaluates and predicts the effects of terraces. N.S. Shaler's monograph on the origin and nature of soils summarized the late 19th century geological concept of soils (Shaler, 1891). In 1906, other details were added by G.P. Merrill.

Near the end of the nineteenth century, Professor Milton Whitney inaugurated the National Soil Survey Program (Jenny, 1961). Professor Whitney and his coworkers in the newly organized soil research unit of the U.S. Department of Agriculture became impressed by the great variations among natural soils—persistent variations that were in no way related to the effects of agricultural use. Whitney and his coworkers emphasized soil texture and the capacity of the soil to furnish plants with moisture as well as nutrients. Professor F.H. King of the University of Wisconsin was also reporting the importance of the physical properties of soils about this time (King, 1910).

Early soil surveys were made to help farmers locate soils responsive to different management practices and to help them decide what crops and management practices were most suitable for the particular kinds of soil on their farms. Many of the early workers were geologists because only geologists were skilled in the necessary field methods and in scientific correlation appropriate to the study of soils. They conceived soils as mainly the weathering products of geologic formations, defined by landform and lithologic composition. Most of the soil surveys published before 1910 were strongly influenced by these concepts. Those published from 1910 to 1920 gradually added greater refinements and recognized more soil features but retained fundamentally geological concepts.

Early field workers soon learned that many important soil properties were not necessarily related to either landform or kind of rock. They noted that soils with poor natural drainage had different properties from soils with good natural drainage and that many sloping soils were unlike level ones. Topography was clearly related to soil profile differences. As early as 1902, soil structure was described in the soil survey of Dubuque County, Iowa. The 1904 soil survey of Tama County, Iowa, reported that, on similar parent material, soils that had formed under forest contrasted markedly with soils that had formed under grass.

The balance-sheet theory of plant nutrition dominated the laboratory and the geological concept dominated field work. Both approaches were taught in many classrooms until the late 1920Õs. Although broader and more generally useful concepts of soil were being developed by some soil scientists, especially E.W. Hilgard (Hilgard, 1860) and G.N. Coffey (Coffey, 1912) in the United States and soil scientists in Russia, the necessary data for formulating these broader concepts came from the field work of the soil survey during the first decade of its operations in the United States. After the work of Hilgard, the longest step toward a more satisfactory concept of soil was made by G.N. Coffey, who determined the ideal classification to be a hierarchical system that was based on the unique characteristics of soil as "a natural body having a definite genesis and distinct nature of its own and occupying an independent position in the formations constituting the surface of the earth" (Cline, 1977).

Beginning in 1870, the Russian school of soil science under the leadership of V.V. Dokuchaiev and N.M. Sibertsev was developing a new concept of soil. The Russian workers conceived of soils as independent natural bodies, each with unique properties resulting from a unique combination of climate, living matter, parent material, relief, and time (Gedroiz, 1927). They hypothesized that properties of each soil reflected the combined effects of the particular set of genetic factors responsible for the soil's formation. Hans Jenny later emphasized the functionally relatedness of soil properties and soil formation. The results of this work became generally available to Americans through the publication in 1914 of K.D. Glinka's textbook in

German and especially through its translation into English by C.F. Marbut in 1927 (Glinka, 1927).

The Russian concepts were revolutionary. Properties of soils no longer were based wholly on inferences from the nature of the rocks or from climate or other environmental factors, considered singly or collectively; rather, by going directly to the soil itself, the integrated expression of all these factors could be seen in the morphology of the soils. This concept required that *all properties* of soils be considered collectively in terms of a completely integrated natural body. In short, it made possible a science of soil.

The early enthusiasm for the new concept and for the rising new discipline of soil science led some to suggest the study of soil could proceed without regard to the older concepts derived from geology and agricultural chemistry. Certainly the reverse is true. Besides laying the foundation for a soil science with its own principles, the new concept makes the other sciences even more useful. Soil morphology provides a firm basis on which to group the results of observation, experiments, and practical experience and to develop integrated principles that predict the behavior of the soils.

Under the leadership of Marbut, the Russian concept was broadened and adapted to conditions in the United States (Marbut, 1921). As mentioned before, this concept emphasized individual soil profiles to the subordination of external soil features and surface geology. By emphasizing soil profiles, however, soil scientists at first tended to overlook the natural variability of soils which can be substantial even within a small area. Overlooking the variability of soils seriously reduced the value of the maps which showed the location of the soils. This weakness soon became evident in the United States, perhaps because of the emphasis here on making detailed soil maps for their practical, predictive value. Progress in transforming the profile concept into a more reliable predictive tool was rapid because a large body of important field data had already been accumulated. By 1925, a large amount of morphological and chemical work was being done on soils throughout the country. The data available by 1930 were summarized and interpreted in accordance with this concept, as viewed by Marbut in his work on the soils of the United States (Marbut, 1935).

Furthermore, early emphasis on genetic soil profiles was so great as to suggest that material lacking a genetic profile, such as recent alluvium, was not soil. A sharp distinction was drawn between rock weathering and soil formation. Although a distinction between these sets of processes is useful for some purposes, rock and mineral weathering and soil formation are commonly indistinguishable.

The concept of soil was gradually broadened and extended during the years following 1930, essentially through consolidation and balance. The major emphasis had been on the soil profile. After 1930, morphological studies were extended from single pits to long trenches or a series of pits in an area of a soil. The morphology of a soil came to be described by ranges of properties deviating from a central concept instead of by a single "typical" profile. The development of techniques for mineralogical studies of clays also emphasized the need for laboratory studies.

Marbut emphasized strongly that classification of soils should be based on morphology instead of on theories of soil genesis, because theories are both ephemeral and dynamic. He perhaps overemphasized this point to offset other workers who assumed that soils had certain characteristics without examining the soils. Marbut tried to make clear that examination of the soils themselves was essential in developing a system of Soil Classification and in making usable soil maps. In spite of this, Marbut's work reveals his personal understanding of the contributions of geology to soil science. His soil classification of 1935 depends heavily on the concept of a "normal soil," the product of equilibrium on a landscape where downward erosion keeps pace with soil formation.

Clarification and broadening of the concept of a soil science also grew out of the increasing emphasis on detailed soil mapping. Concepts changed with increased emphasis on predicting crop yields for each kind of soil shown on the maps. Many of the older descriptions of soils had not been quantitative enough and the units of classification had been too heterogeneous for making yield and management predictions needed for planning the management of individual farms or fields.

During the 1930s, soil formation was explained in terms of loosely conceived processes, such as "podzolization," "laterization," and "calcification." These were presumed to be unique processes responsible for the observed common properties of the soils of a region (Jenny, 1946).

In 1941 Hans Jenny's *Factors of Soil Formation*, a system of quantitative pedology, concisely summarized and illustrated many of the basic principles of modern soil science to that date (Jenny, 1941). Since 1940, time has assumed much greater significance among the factors of soil formation, and geomorphological studies have become important in determining the time that soil material at any place has been subjected to soil-forming processes. Meanwhile, advances in soil chemistry, soil physics, soil mineralogy, and soil biology, as well as in the basic sciences that underlie them, have added new tools and new dimensions to the study of soil formation. As a consequence, the formation of soil has come to be treated as the aggregate of many interrelated physical, chemical, and biological processes. These processes are subject to quantitative study in soil physics, soil chemistry, soil mineralogy, and soil biology. The focus of attention also has shifted from the study of gross attributes of the whole soil to the co-varying detail of individual parts, including grain-to-grain relationships.

In both the classification of Marbut and the 1938 classification developed by the U.S. Department of Agriculture, the classes were described mainly in qualitative terms. Classes were not defined in quantitative terms that would permit consistent application of the system by different scientists. Neither system definitely linked the classes of its higher categories, largely influenced by genetic concepts initiated by the Russian soil scientists, to the soil series and their subdivisions that were used in soil mapping in the United States. Both systems reflected the concepts and theories of soil genesis of the time, which were themselves predominantly qualitative in character. Modification of the 1938 system in 1949 corrected some of its deficiencies but also illustrated the need for a reappraisal of concepts and principles. More than 15 years of work under the leadership of Guy Smith culminated in a new soil classification system. This became the official classification system of the U.S. National Cooperative Soil Survey in 1965 and was published in 1975 as *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys* (Soil Survey Staff, 1975).

Categories and classes of the new taxonomy are direct consequences of new and revised concepts and theories. The system of soil classification discussed in *Soil Taxonomy* is dynamic and will change as new knowledge is obtained. Its most significant contribution comes from defining class limits quantitatively. The theories on which the system is based are tested every time the taxonomy is applied. For soil survey, the application of quantitatively defined classes to bodies of soil produces quantitatively defined mapping units. This permits the soil maps to be interpreted with more precision than was formerly achieved. Furthermore, this soil-classification system simplifies and accelerates the process of soil correlation.

In addition to the new soil classification system, several other techniques have contributed to the increased precision of soil survey. The use of aerial photographs as mapping bases became almost universal in detailed soil mapping during the late 1930s and early 1940s. Using aerial photographs has greatly increased the precision with which soil boundaries can be delineated on maps. At the same time, the scale of published maps was increased from about 1:63,360 to 1:24,000 to 1:15,840. The smallest area that can be delineated legibly at a scale of 1:63,360 is about 15.8 ha; areas of 1 ha can be delineated legibly at a scale of 1:15,840.

Another factor has had an immense impact on soil survey, especially during the 1960s. Before 1950, the primary applications of soil surveys were farming, ranching, and forestry. Applications for highway planning were recognized in some States as early as the late 1920s, and soil interpretations were placed in field manuals for highway engineers of some States during the 1930s and 1940s. Nevertheless, the changes in soil surveys during this period were mainly responses to the needs of farming, ranching, and forestry. During the 1950s and 1960s nonfarm uses of the soil increased rapidly. This created a great need for information about the effects of soils on those nonfarm uses.

Beginning about 1950, cooperative research with the Bureau of Public Roads and State highway departments established a firm basis for applying soil surveys to road construction. Soil scientists, engineers, and others have worked together to develop interpretations of soils for roads and other nonfarm uses. These interpretations, which have become standard parts of published soil surveys, require different information about soils. Some soil properties that are not important for growth of plants are very important in evaluating soils for building sites, sewage disposal systems, highways, pipelines, and recreation. Many of these uses of soil require very large capital investments per unit area; errors can be extremely costly. Consequently, the location of soil boundaries, the identification of the areas delineated, and the quantitative definition of map units have assumed great importance.

Modern Concept of Soil

Soil is "the collection of natural bodies in the earth's [sic] surface, in places modified or even made by man of earthy materials, containing living matter and supporting or capable of supporting plants out-of-doors. Its upper limit is air or shallow water. At its margins it grades to deep water or to barren areas of rock or ice. Its lower limit to the not-soil beneath is perhaps the most difficult to define. Soil includes the horizons near the surface that differ from the underlying rock material as a result of interactions, through time, of climate, living organisms, parent materials, and relief. In the few places where it contains thin cemented horizons that are impermeable to roots, soil is as deep as the deepest horizon. More commonly soil grades at its lower margin to hard rock or to earthy materials virtually devoid of roots, animals, or marks of other biologic activity. The lower limit of soil, therefore, is normally the lower limit of biologic activity, which generally coincides with the common rooting depth of native perennial plants" (Soil Survey Staff, 1975).

The "natural bodies" of this definition include all genetically related parts of the soil. A given part, such as a cemented layer, may not contain living matter or be capable of supporting plants. It is, however, still a part of the soil if it is genetically related to the other parts and if the body as a unit contains living matter and is capable of supporting plants.

The definition includes as soil all natural bodies that contain living matter and are capable of supporting plants even though they do not have genetically differentiated parts. A fresh deposit of alluvium or earthy constructed fill is soil if it can support plants. To be soil, a natural body must contain living matter. This excludes former soils now buried below the effects of organisms. This is not to say that buried soils may not be characterized by reference to taxonomic classes. It merely means that they are not now members of the collection of natural bodies called soil; they are buried paleosols.

Not everything "capable of supporting plants out-of-doors" is soil. Bodies of water that support floating plants, such as algae, are not soil, but the sediment below shallow water is soil if it can support bottom-rooting plants such as cattails or reeds. The above-ground parts of plants are also not soil, although they may support parasitic plants. Rock that mainly supports lichens on the surface or plants only in widely spaced cracks is also excluded.

The time transition from not-soil to soil can be illustrated by recent lava flows in warm regions under heavy and very frequent rainfall. Plants become established very quickly in such climates on the basaltic lava, even through there is very little earthy material. The plants are supported by the porous rock filled with water containing plant nutrients. Organic matter soon accumulates; but, before it does, the dominantly porous broken lava in which plant roots grow is soil.

More than 50 years ago, Marbut's definition of soil as "the outer layer" of the Earth's crust implied a concept of soil as a continuum (Marbut, 1935). The current definition refers to soil as a collection of natural bodies on the surface of the Earth, which divides Marbut's continuum into discrete, defined parts that can be treated as members of a population. The perspective of soil has changed from one in which the whole was emphasized and its parts were loosely defined to one in which the parts are sharply defined and the whole is an organized collection of these parts.

Factors that Control the Distribution of Soils

The properties of soil vary from place to place, but this variation is not random. Natural soil bodies are the result of climate and living organisms acting on parent material, with topography or local relief exerting a modifying influence and with time required for soil-forming processes to act. For the most part, soils are the same wherever all elements of the five factors are the same. Under similar environments in different places, soils are similar. This regularity permits prediction of the location of many different kinds of soil.

When soils are studied in small areas, the effects of topography or local relief, parent material, and time on soil becomes apparent. In the humid region, for example, wet soils and the properties associated with wetness are common in low-lying places; better drained soils form in most instances in higher lying areas. The correct conclusion is that *topography* or *relief* is important. In arid regions, the differences associated with relief may be salinity or sodicity, but the conclusion is the same. In a local environment, different soils are associated with contrasting parent materials, such as residuum from shale and from sandstone, and the correct conclusion is that *parent material* is important. Soils on a flood plain differ from soils on higher and older terraces where there is no longer deposition of parent material on the surface. The correct conclusion is that *time* is important. The influence of topography, parent material, and time on the formation of soil is observed repeatedly while studying the soils of an area.

With the notable exception of the contrasting patterns of vegetation in transition zones, local differences in vegetation are closely associated with differences in relief, parent material, or time. The effects of microclimate on vegetation may be reflected in the soil, but such effects are likely associated with differences in local relief.

Regional climate and vegetation influence the soil as well as topography or relief, parent material, and time. In spite of local differences, most of the soils in an area typically have some properties in common. The low-base status of many soils in humid or naturally acid rock or sediment regions stands in marked contrast to the typical, high-base status in arid or calcareous sandstone or limestone regions. To one who has studied soils only on old landscapes of humid regions, however, low base status is so commonplace that little significance is attached to it.

Regional patterns of climate, vegetation, and parent material can be used to predict the kinds of soil in large areas. The local patterns of topography or relief, parent material, and time, and their relationships to vegetation and microclimate, can be used to predict the kinds of soil in small areas. Soil surveyors learn to use local features, especially topography and associated vegetation, as marks of unique combinations of all five factors. These features are used to predict boundaries of different kinds of soil and to predict some of the properties of the soil within those boundaries.

Soil-Landscape Relationships

Geographic order suggests natural relationships. Running water, with weathering and gravitation, commonly sculptures landforms within a landscape. Over the ages, earthy material has been removed from some landforms and deposited on others. Landforms are interrelated. An entire area has unity through the interrelationships of its landforms.

Each distinguishable landform may have one kind of soil or several. Climate, including its change with time, commonly will have been about the same throughout the extent of a minor landform. The kinds of vegetation associated with climate also likely will have been fairly uniform. Relief varies within some limits that are characteristic of the landform. The time that the material has been subjected to soil formation has probably been about the same throughout the landform. The surface of the landform may extend through one kind of parent material and into another. Of course, position on the landform may have influenced soil-water relationships, microclimate, and vegetation.

Just as different kinds of soil are commonly associated in a landscape, several landscapes are commonly associated in still larger areas. These areas cover thousands or tens of thousands of square kilometers. Many can be identified on photographs taken from satellites. From this vantage point, broad geomorphic units—the East Gulf Coastal Plain, the Allegheny Plateau, the Laramie Basin, and the Great Valley of California—are apparent. These broad units usually have some unity of landscape, which is characterized by such terms as "plain," "plateau," and "mountain." These physiographic units are composed of many kinds of soil.

The main relief features of a physiographic unit are usually the joint products of deep-seated forces and a complex set of surface processes that have acted over long spans of time. Within a physiographic unit, groups of minor landforms are shaped principally by climate-controlled processes. The climate and biological factors, however, vary much less within a geomorphic unit than across a continent.

Still broader than the geomorphic units are great morphogenetic regions having distinctive climates. For example, one classification recognizes glacial, periglacial, arid, semiarid-subhumid, humid-temperate, and humid-tropical climatic regions associated with distinctive sets of geomorphic processes. Other major regions characterized by seasonal climatic variation are also recognized. These geomorphic-climatic regions are related to soil moisture and soil temperature regimes.

Thus, the great climatic regions are divided into major geomorphic units. Landforms and associated soil landscapes are small parts of these units and are commonly of relatively recent origin.

The landforms of concern in soil mapping may include constructional units, such as glacial moraines, and elements of local sequences of graded erosional and constructional land surfaces. These bear the imprint of local, base-level controls under climate-induced processes. Most surfaces that have formed within the last 10,000 years have been subject to climatic and base-level controls similar to those of the present. Older surfaces may retain the imprint of climatic conditions and related vegetation of the distant past. Most landforms of the present started to form during the Quaternary Period; some started in late Tertiary time. In many places conditions of the past differed significantly from those of the present. Understanding climatic changes locally and worldwide far into the past contributes to understanding the attributes of landforms in the present.

Geomorphic processes are important in mapping soils. Soil scientists need a working knowledge of local geomorphic relationships in areas where they map and should understand the interpretations of landforms and land surfaces made by geomorphologists. The intricate interrelationships of soil and landscape are best studied by a collaboration between soil scientists and geomorphologists.

Development of the Soil Survey

Soil surveys were authorized in the United States by the U.S. Department of Agriculture Appropriations Act for fiscal year 1896, which provided funds for an investigation "of the relation of soils to climate and organic life" and "of the texture and composition of soils in field and laboratory."

In 1899 the U.S. Department of Agriculture completed field investigations and soil mapping of portions of Utah, Colorado, New Mexico, and Connecticut. Reports of these soil surveys and similar works were published by legislative directive. At the same time, the State of Maryland, using similar procedures and State funds, completed a soil survey of Cecil County. Since then many soil surveys have been initiated, completed, and published cooperatively by the Department of Agriculture, State agencies, and other Federal agencies. The total effort is the National Cooperative Soil Survey (NCSS).

The early soil surveys investigated the use of soils for farming, ranching, and forestry. As experience was acquired in the use of soil surveys, predictions were made about other uses, such as highways, airfields, and residential and industrial developments. As the making and the use of soil surveys expanded, the knowledge about soils—about their nature, occurrence, and behavior for defined uses and management—also increased. The Highway Department of Michigan was applying soil survey experience to assist in planning highway construction in the late 1920s. At about the same time soil surveys in North Dakota were used in tax assessment.

Soil surveys published between 1920 and 1930 reveal a marked transition from earlier concepts to give emphasis to soil profiles and soils as independent bodies. The maps retained significant geologic boundaries as soil maps do today. Many of the surveys of that period provide excellent general maps for evaluating engineering properties of geologic material. In addition, maps and texts of the period show more recognition of other soil properties significant to farming and forestry than do earlier surveys and have value for broad generalizations about farming practices in large areas.

The use of aerial photographs for soil mapping, which began during the late 1920s and early 1930s, greatly increased the precision of plotting soil boundaries. To meet the needs for planning the management of individual fields and farms, greater precision of interpretation was required. The changing objectives of soil surveys initiated changes in methods and techniques that made surveys more useful and forced reconsideration of the concept of soil itself.

Beginning in the 1930s, the Soil Conservation Service (SCS) emphasized the control of soil erosion as it used soil surveys for the resource conservation planning of farms and ranches. In the 1950s, extensive use was made of soil survey information in urban land development in Fairfax County, Virginia, and in the subdivision design of suburban areas of Chicago, Illinois. Soil surveys were an important base for resource information in regional land-use planning in southeastern Wisconsin. Rural land zoning has also relied on soil surveys.

Soil surveys necessarily involve thousands of different kinds of soils—as many as there are significantly different combinations of genetic factors. The history of a soil and evidence of its potential for use are contained in the properties soil scientists are able to identify through observation and research in the field and laboratory. These properties determine the limitations, suitability, and potential for rural and urban land use of soils. Soil surveys are particularly valuable because they identify specific soil properties and help soil scientists make broad generalizations significant to farming and forestry practices.

The program of the NCSS can be divided into soil mapping, description of the mapping concepts, and the prediction of the behavior of these mapping concepts for various uses. Soil behavior prediction relies on the evaluated and named soil properties to interpret the concept of map units.

Soil Survey and the Soil Map

The different kinds of soil used to name soil map units have sets of interrelated properties that are characteristic of soil as a natural body. This definition is intended to exclude maps showing the distribution of a single soil property such as texture, slope, or depth, alone or in limited combinations; maps that show the distribution of soil qualities such as productivity or erodibility; and maps of soil-forming factors, such as climate, topography, vegetation, or geologic material. A soil map delineates areas occupied by different kinds of soil, each of which has a unique set of interrelated properties characteristic of the material from which it formed, its environment, and its history. The soils mapped by the NCSS are identified by names that serve as references to a national system of soil taxonomy.

The geographic distribution of many individual soil properties or soil qualities can be extracted from soil maps and shown on separate maps for special purposes, such as showing predicted soil behavior for a particular use. The number of such interpretative maps that can be derived from a soil map is large, and each such map would differ from the others according to its purpose. A map made for one specific interpretation can rarely serve a different purpose.

Maps to show one or more soil properties can be made directly from field observations without making a basic soil map. Such maps serve their specific purposes but have few other applications. Predictions of soil behavior can also be mapped directly; however, most such interpretations need to be changed with changes in land use and in the cultural and economic environment. A map showing the productivity of crops on soils that are wet and undrained, for example, has little value after drainage systems have been installed. If the basic soil map is made accurately, interpretative maps can be revised as needed without doing additional fieldwork. In planning soil surveys, this point needs to be emphasized. Occasionally, "short-cut" inventories are made for some narrow objective, perhaps at a cost lower than that of a soil survey. Such maps quickly become obsolete. They cannot be revised without fieldwork because vital data are missing, facts are mixed with interpretations, or boundaries between significantly different soil units have been omitted.

The basic objective of soil surveys is the same for all kinds of land, although the number of mapping units, their composition, and the detail of mapping vary with the complexity of the soil patterns and the specific needs of the users. Thus a soil survey is matched to the soils and the soil-related problems of the area. Soil surveys increase our general knowledge about soils and serve practical purposes. They satisfy a need for soils information about specific geographic areas for State, county, and community land-use plans. These plans include resource conservation plans for farms and ranches, development of reclamation projects, forest management, engineering projects, as well as other purposes.

The storage and retrieval of soil survey data are possible through the use of Automatic Data Processing (ADP). ADP helps develop important interpretations and policy decisions for both the present and the future.